

Cost-Effective TiAl based Materials

V.S. Moxson¹, Fusheng Sun², V. Duz¹, Susan L. Draper³, and F.H. (Sam) Froes²

1. ADMA Products, Inc., 8180 Boyle Pkwy., Twinsburg, OH44087, USA
2. University of Idaho, Inst. for Matls. & Adv. Proc. (IMAP), Mines Bldg. Rm. 321, Moscow, ID 83844-3026 USA;
3. NASA Glenn Research Center, 21000 Brookpark Rd., MS 49-1, Cleveland, OH 44135 USA

Abstract

Because of their inherent low ductility, TiAl-based materials are difficult to fabricate, especially thin gage titanium gamma aluminide (TiAl) sheet and foil. In this paper, an innovative powder metallurgy approach for producing cost-effective thin gage TiAl sheets (with 356 mm long and 235 mm wide, and a thickness of 0.74, 1.09, 1.55, and 2.34 mm, respectively) is presented. The microstructures and tensile properties at room and elevated temperatures of the thin gage TiAl are studied. Results show that these TiAl sheets have a relatively homogenous chemistry, uniform microstructure, and acceptable mechanical properties. This work demonstrates a cost-effective method for producing both flat products (sheet/foil) and complex "chunky" parts of TiAl for various advanced applications including aerospace and automotive industries.

INTRODUCTION

Gamma titanium aluminides (TiAl) alloys have received much attention from both the aerospace and automotive industries due to their high specific strength and stiffness and their oxidation resistance [1-5]. The typical TiAl production method was based on ingot metallurgy (IM) and consists of VAR (Vacuum Arc Remelt) ingot production, its hot isostatic forging, cut and machine the forgings into a rectangle bar, which was encapsulated, hot rolled down to the desired thickness, and, then, de-canning and finished ground to final thickness. The cost of the sheet was too high (in the range of \$10,000/lb) because of the high forging rejection rate and manufacturing cost. Research activities have been focused to improve the manufacturing steps and improve a consistency of properties between sheets. Powder metallurgy (PM) approach has been investigated as a lower cost method of producing complex, near net shape components [6, 7]. This development focused attention on developing an innovative PM method, but commercially viable conversion practice for cost effective gamma-titanium aluminide materials to produce controlled, uniformly refined sheet structures with optimum mechanical properties in final PM products. TiAl sheet material named Gamma-met

developed by a team of researchers from NASA, Pratt & Whitney, and Plansee by innovative sheet rolling technique, novel component hot-forming method, and pioneering material joining approached offers $1/10^{\text{th}}$ the cost of the IM manufacturing [8]. The composition of Gamma-met was developed to provide better rolling characteristics and improved post rolling mechanical properties and it is projected that cost of Gamma-net TiAl sheet produced by this innovative approach will soon have cost competing with titanium alloys, i.e. in the range of \$150.00/lb. However, it is reported that the P/M processing root for Gamma-met includes consolidation of powder into a rectangular pre-material blank, machining the blanks and their encapsulation, rolling, decanning, and final grinding, which are still rather expensive manufacturing steps.

✓
too much
precision!

Gamma TiAl sheet and foil evaluated in this article were produced by fewer steps that it is described for Gamma-met process and three expensive operations – consolidation of powder into a rectangular pre-material blank, machining the blanks, encapsulation of the blank, and decanning were completely eliminated. This innovative process, called ADMA-22TM, offers the cost of finished sheets and foils in the range of 1.1-1.2% of raw material cost (prealloyed TiAl or Blended Elemental TiAl powders) and substantially below of the cost of IM titanium alloy sheet. ADMA-22TM process is applicable to any TiAl composition regardless of alloying elements or addition of whiskers or other strengthening particulates.

EXPERIMENTAL PROCEDURE

Cost-effective TiAl sheets with a thickness of 0.74, 1.09, 1.55, and 2.34 mm, respectively, were manufactured by an ADMA Products, Ohio, proprietary powder metallurgy process—an innovative loose sintering followed by hot consolidation approach at elevated temperatures using Crucible GA powder Ti-48Al-2Cr-2Nb. The chemical analysis for this powder is 31.8 wt% Al, 2.7 wt% Cr, and 4.8 at% Nb, 0.107 wt% O, and 0.007 wt% N with a mesh of -100 (less than 150 micro). The TiAl sheets are approximately 356 mm long and 235 mm wide. Specimens were cut for metallographic investigations and tensile tests. The samples, with 30 mm in gage length and 6 mm in wide, were ground and polished. The microstructure was investigated using optical microscopy (OM) technique (Olympus PMG-3) after etching in a mixture of 1% HF, 3% HFO₃ and 96% H₂O. The mechanical properties were determined under tensile test conditions at temperatures of 23, 650, 704, 815°C. The fracture surfaces were examined by scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

The aim of this work was first to demonstrate the feasibility for producing Ti-48Al-2Cr-2Nb (at%) sheets using the cost effective PM process developed in ADMA Products, and subsequently to characterize the microstructure and mechanical properties of the sheet products.

Microstructure

Initial sheet manufacturing trials were made with four PM compacted sheet preforms with a thickness of 0.74, 1.09, 1.55, and 2.34 mm, respectively, and then the preforms were subsequently loose sintered. Figure 1 shows the microstructure of the Ti-48Al-2Cr-2Nb (at%) alloy after sintering. As shown in Figure 1a, the as-sintered sheet has a microstructure consisting of spherical powders and 10-15% volume fraction porosity. Some lamellar structures were observed in the spherical powders after sintering (as shown in Figure 1b).

The as-sintered sheets were subsequently subjected to hot consolidation, and then furnace cooling to room temperature. As shown in Figures 2a and 2b, a fully lamellar microstructure was obtained in the hot-consolidation Ti-48Al-2Cr-2Nb sheets with an average grain size approximately 200 micron. No porosity was observed in the as-hot-consolidation sheets. The low-magnification photomicrostructure of the as-hot-consolidation sheet seen in Figure 3 shows that the fully lamellar microstructure is homogenous in the cross section.

Tensile Testing

The tensile samples were prepared from both the longitudinal and transverse section of the hot-consolidation sheets. Mechanical properties of the sheets were studied by conducting tensile testing at 23, 650, 704, and 815°C, respectively. Table I shows the tensile testing results of the Ti-48Al-2Cr-2Nb sheets with an average grain size of 20 micron, produced by elevated temperature sintering and hot-consolidation. The Young's modulus is decreased with increasing tensile testing temperature. At room temperature, the longitudinal section and transverse section of the sheet have the similar yield strength level, while the ultimate tensile strength from the transverse section is higher than that from the longitudinal section. With increasing tensile testing temperature, the yield strength is gradually decreased, but the ultimate tensile strength is increased at 650 and 704°C.

Table I Tensile results of the P/M TiAl sheet (Ti-48Al-2Cr-2Nb at%)

Temperature	Sample	E, GPa (msi)	YS, MPa (ksi)	UTS, MPa (ksi)	EL., %
23°C (75°F)	T	201 (29.1)	386 (56.0)	450 (65.2)	0.55
	L	193 (27.9)	382 (55.4)	406 (58.9)	0.31
650°C (1200°F)	T	195 (28.2)	327 (47.4)	463 (67.2)	1.60
	L	145 (21.0)	318 (46.1)	471 (68.3)	1.51
704°C (1300°F)	T	182 (26.4)	332 (48.2)	460 (66.6)	1.80
	L	155 (22.5)	335 (48.6)	473 (68.6)	1.69
815°C (1500°F)	T	195 (28.2)	333 (48.3)	410 (59.3)	23.5
	L	167 (24.2)	317 (45.9)	380 (55.1)	7.04

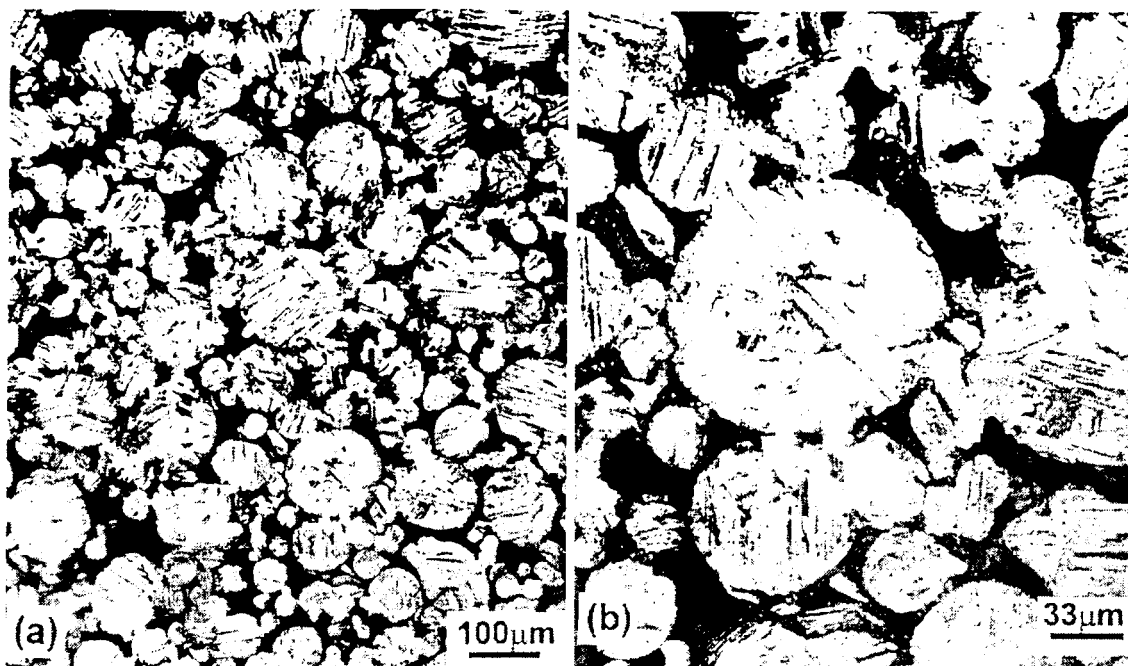


Figure 1 Microstructures of the Ti-48Al-2Cr-2Nb (at%) alloy after sintering

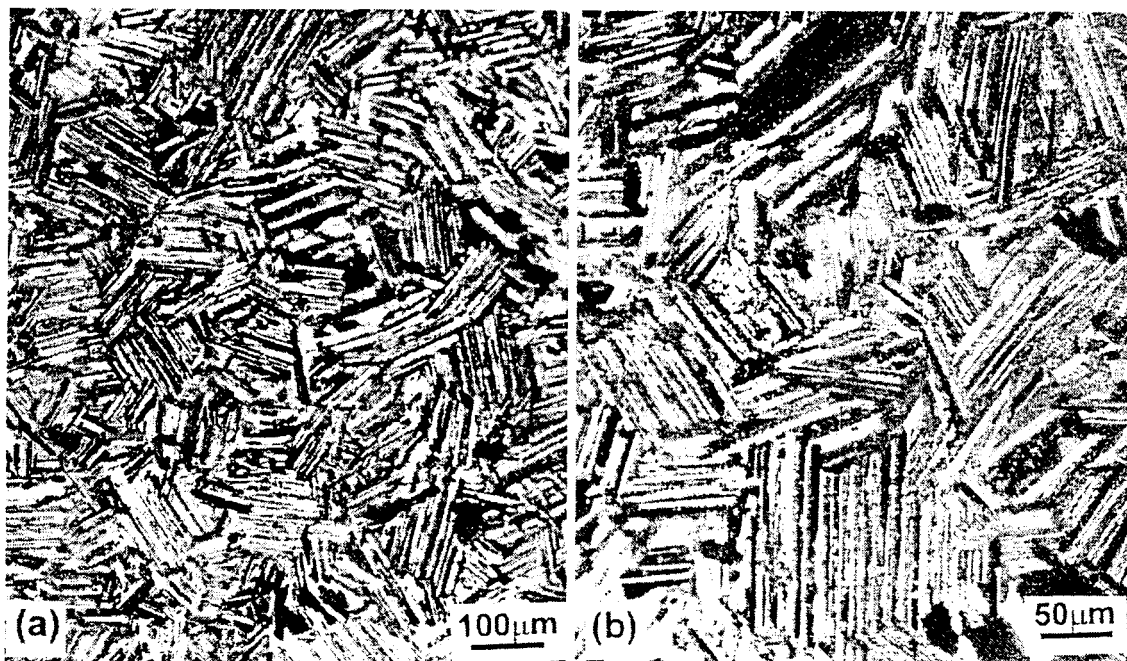


Figure 2 Microstructures of the Ti-48Al-2Cr-2Nb (at%) sheet after hot consolidation.

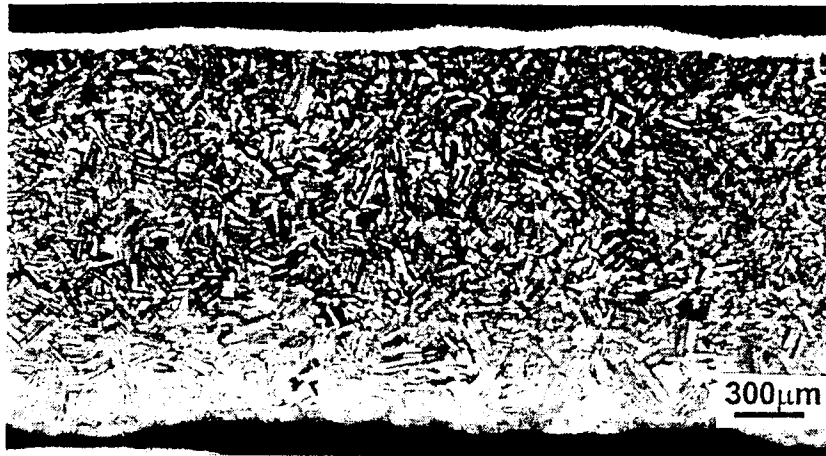


Figure 3 Low-magnification microstructures of the Ti-48Al-2Cr-2Nb (at%) sheet after hot consolidation, showing a uniform fully lamellar microstructure.

Fractography

Figure 4 is a typical micrograph from a tensile sample fractured at room temperature and studied in the SEM. It is clearly that the transgranular cleavage is the main mode of failure. The room temperature tensile fracture surfaces were typified by flat facets indicative of cleavage fracture in gamma phase (Figure 4a), and featureless facets indicative of interlamellar splitting or stepped features, formed as a result of cleaving across the laths (Figure 4b). Figures 5a and 5b show a typical fracture surface after 650°C tensile testing. The fracture of the Ti-48Al-2Cr-2Nb sheet is a mixture of cleavage and interface failure. The elongated cleavage facets corresponding to gamma lamellae, and secondary crack along gamma/gamma lamellar and colonies boundaries were observed in Figure 5a and 5b. Figure 6 shows the fracture surface after 815°C tensile testing, in addition to cleavage facets.



(continued)



Figure 4 Typical tensile fracture surfaces after tensile testing at room temperature.

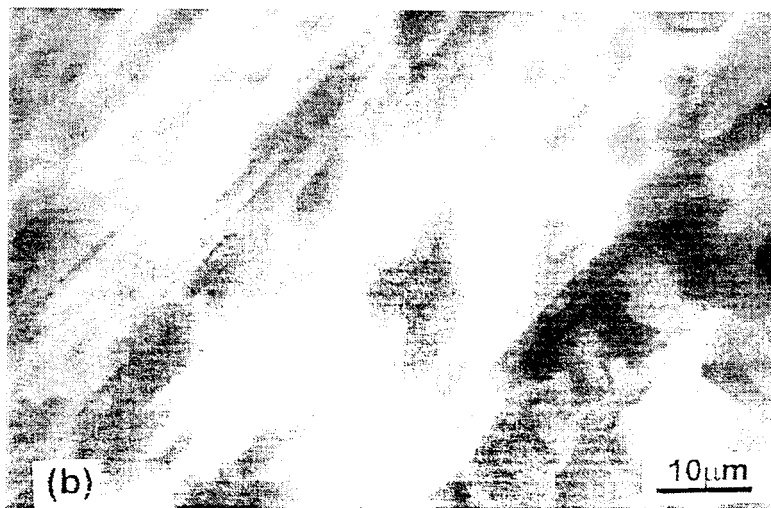


Figure 5 Typical fracture surfaces after tensile testing at 650°C.

Low Cost and Future Work

Preliminary gamma titanium aluminide sheets, with 356 mm long and 235 mm wide, and a thickness in a range of 0.74-2.34 mm, has been produced on-shore in a collaborative program between ADMA Products, Inc., University of Idaho, and NASA Lewis using an innovative PM approach. Evaluations of the sheets indicated that they had a relatively homogenous chemistry, uniform microstructure, acceptable mechanical properties, and low-cost. While this sheet is far from optimized, future work is required to optimize both the processing regimes and final microstructure. For example, a fully lamellar structure leads to lower ductility at room temperature. The relative lower ductility at room temperature may result from the large gamma/gamma lamellar spacing, since the strength and ductility of TiAl alloys are associated with both the grain size and lamellar spacing. With optimization of heat treatment, both the strength and ductility will be further improved.



Figure 5 Typical fracture surfaces after tensile testing at 815°C.

The development of a cost-effective innovative PM process is potentially attractive for producing thin gauge TiAl sheet and foil for aerospace and automotive applications. Although TiAl alloys possess attractive high-temperature strength and creep properties, their poor intermediate and room temperature ductility cause conventional manufacturing operations such as rolling, forging, or drawing to be difficult for titanium aluminides. This innovative PM approach can provide cost effective TiAl sheet and foil. In addition, complex shape “chunky” parts such as automobile connecting rods can be fabricated by this innovative approach.

CONCLUSIONS

A cost-effective innovative loose sintering and hot consolidation approach has been evaluated for producing TiAl sheets. Fully density TiAl sheets with different gauges have successfully been manufactured. A relatively homogenous chemistry, uniform microstructure, and acceptable mechanical properties have been obtained in the cost effective TiAl sheets, and further improvements of the mechanical properties of the TiAl sheets can be obtained through optimization of the processing.

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